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UNITED STATES NAVAL POSTGRADUATE SCHOOL

DEPARTMENT OF AERONAUTICS

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CALIBRATION AND OPERATION
OF THE
BOEING TURBOPROP ENGINE
In The Outdoor Test Facility

by

H. D. HARDY

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PREPARED BY: ______________________ March 1964
H. D. Hardy

APPROVED BY: ______________________ March 1964
R. E. McConnell

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1. INTRODUCTION:

The data herein gives the procedures for exact calibration and safe operation of the subject powerplant installation. A list of the instrumentation available, the engine performance specifications and additional data for engine cycle analysis are included. This report will be revised periodically to reflect any changes in engine configuration or facility instrumentation. Although it is intended that this data be sufficient to enable any authorized personnel to operate the subject engine in this test stand, it is requested that all tests be conducted with the aid of a qualified staff technician.

The outdoor test complex for the turboprop engine is located at the East side of Building 230, as shown in Figure No. 1. The engine stand is positioned in the enclosed run-up area and the control of the engine is governed from the adjacent blockhouse. The engine is positioned to face into the prevailing wind, however, Building 230 reduces the effects due to gusts. The propeller slipstream and the engine exhaust gases are directed on to an open field which extends for approximately 600 feet beyond the test area.

2. TEST EQUIPMENT DESCRIPTION:

Engine: The gas turbine powerplant under investigation is a turboprop engine developed by the Boeing Aircraft Company which utilizes two separate power conversion units, a gas generator and a power output section for the propeller. The gas generator contains a centrifugal compressor, two interconnected combustion chambers and a single-stage axial-flow turbine. The high energy mass flow expelled from this unit passes into the power output section which houses a free-wheeling single-stage axial-flow turbine that drives the propeller shaft through a gear reduction train. See Figure No. 2.

Since the two turbine rotors are not mechanically coupled, the gas generator and the power output section may exhibit independent rotor speeds, resulting in a wide operational spectrum. The basic Sea Level performance ratings are as follows:

Rating	SHP	Gas Gen. RPM	Output Turb. RPM	Prop. RPM	EGT °F	SFC PPH/HP	Airflow PPS
Take-off	210	37,000	26,600	2450	1275	1.29	3.75
Continuous	175	36,500	25,000	2300	1200	1.35	3.68

Propeller: The propeller, Beech Model A-35, presently installed on the turboprop engine can be controlled manually or can be set for automatic adjustment to maintain a constant RPM. The propeller pitch can be varied from 11^{o} to 28^{o} by operation of the pitch control switch on the control console. (Fig. 2)

Engine Test Stand: The turboprop engine is mounted on a specially designed transportable support stand for ease of storage and maintenance. The main assembly supports the box-shaped engine mounting frame by means of a flexure-beam located in the vertical plane of the engine. This pivotal support permits the flexing of the engine and the measurement of the propeller thrust as well as the torque of the propulsion system. An SR-4 load cell is utilized for thrust indication, while a hydraulic actuator transmits the torque values to a pressure gauge. (Figs. 3 and 4)

Engine Control Room: The engine is controlled from the blockhouse adjacent to the testing ramp. The operator must view the engine through a mirror arrangement since a steel protective panel has been erected between the ramp and the control room. (Fig. 5)

The engine control panel contains the electrical power switches, the engine controls and the propeller controls. This console and the adjacent instrumentation panel contain the following instruments for engine analysis (Figs. 6 and 7):

Quantity	Units	Instrument
Gas Generator Speed	RPM	Berkley Counter
Propeller Speed	RPM	Berkley Counter
Thrust	(Arbitrary Units)	Budd Strain Indicator
Torque	(Arbitrary Units)	Pressure Gauge
Fuel Flow	Lb/Hr	Vertical Column Flowrater
Oil Pressure	PSIG	Pressure Gauge (0-100)
Fuel Pressure	PSIG	Pressure Gauge (0-1000)
Compr. Inlet Press.	In H_2O	Manometer
Compr. Disch. Press.	In Hg	Wallace Tiernan (manifold)
Burner Outlet Press.	In Hg	" " "
Power Turbine in Press.	In Hg	" " "
Engine Exhaust Press.	In Hg	" " "
Barometric Pressure	In Hg	Barometer
Compr. Inlet Temp.	^{o}F	Thermometer
Compr. Disch. Temp.	^{o}F	Brown Recorder

Quantity	Units	Instrument
Burner Outlet Temp.	^{o}F	Brown Recorder
Exhaust Gas Temp.	^{o}F	" "

3. CALIBRATION PROCEDURE:

The pressure and temperature instruments listed above should require no calibration for an indefinite period. These instruments have been cross-checked with qualified instrumentation with satisfactory results. The two tachometers as well as the fuel flow indicator should require no further calibration unless a malfunction is suspected.

The Thrust and Torque indication systems should be calibrated at the beginning of each term in which the engine will be utilized for cycle analysis. However, if the load cell (thrust) or the hydraulic cylinder (torque) are removed or adjusted, then a re-calibration will be necessary before further testing. The physical arrangement of these two systems are shown in Figure 8. The following steps should be utilized during calibration:

(a) The engine installed in the support stand should be aligned with the centerline of the thrust load cell. The complete assembly should be leveled as close as possible to a true vertical reference. Use of a surveyors transit is recommended for the alignment. The torque hydraulic cylinder should be positioned perpendicular to the thrust load cell and to the vertical reference.

(b) To calibrate the thrust load cell, install a C and S Strain Indicator which is coupled to a hydraulic loading cylinder. This unit should be positioned between the support stand and the engine mounting frame as shown in Figure No. 8. This load must be applied directly along the verticle plane of the engine centerline. Alignment marks have been provided. The actual force applied by the hydraulic piston can be observed on the Cox Datatran Indicator. The resultant indicated force should be displayed on the Budd Strain Indicator.

The force should be applied in increments of 50 lbs. and should range up to a total of 800 lbs. The force should be reduced in similar increments to check for hysteresis. The relationship of applied thrust and load cell indication is shown in Figure 9. This curve, dated 4 March 64, is satisfactory for use during the 4th term beginning on 15 March 64.

CAUTION: The applied thrust depicted in Figure 9 is NOT the actual thrust of the engine. Due to the moment-arms created by the stand linkage which are coupled to the vertical force component emanating from the engine exhaust ducts, a moment (Ft-Lbs) is developed that causes the indicated thrust value to be lower than the true thrust. Linkage dimensions and the exhaust thrust component are discussed further in the Data Analysis Section.

(c) To calibrate the torque measuring system, it is necessary to apply lead shot bags of known weight to the 38.0 inch calibrating lever-arm as shown in Figure 8. Approximately ten (each) ten-lb bags of shot will be required to simulate the complete range of engine torque. These weights should be removed in the exact reverse sequence as applied so as to check for hystersis in the pressure gauge and cylinder. The torque applied and the resulting hydraulic pressures are shown in Figure 10. It should be noted that the data contained in Figure 10, dated 10 March 64, is satisfactory for use during the 4th term beginning 15 March 64.

CAUTION: There is no additional correction necessary to the torque values presented in Figure 10. The exhaust gas vertical force component does not appreciably effect the torque readings. Therefore, these torque data may be used directly to calculate the shaft horsepower developed by the power-plant and the propeller.

4. ENGINE OPERATION PROCEDURE:

Pre-start: Prior to the operation of the engine, the "Pre-start" checks outlined below should be accomplished:

(a) Check ease of rotation of the output turbine and the reduction gear train by rotating the propeller slowly by hand in the direction of normal operat (clockwise).

(b) Check the compressor inlet for foreign objects and the over-all condition of the engine, i.e., fuel and oil leakage.

(c) Check the engine oil level. Fill, if necessary, to the FULL mark on the dipstick. Do NOT overfill.

(d) Check the fuel supply and insure that the fuel valve is open. Make sure that the fuel valve on the engine is closed before starting.

(e) Check the electrical power to the engine and insure that the engine Start Switch is open.

(f) Position RPM Master Switch to "Gas Generator".

(g) Check the engine throttle and propellor actuator for smoothness of operation. The throttle should be in the OFF position and the propeller should be in flat pitch.

(h) Insure that no personnel are in the test area during the engine start.

Engine Starting:

(a) Turn ON electrical power. (110 VAC and 24 VDC)

(b) Turn ON Fuel Boost Pump Switch and the Fuel-to-Engine Switch. Check for fuel flow in the vertical column flowrater.

(c) Turn the Propeller Master Switch ON

(d) Actuate Engine Starter Switch. The gas generator should rotate at 4500 RPM and the fuel pressure should be at least 30 PSI.

CAUTION: Do NOT attempt a start if these limits are not realized.

(e) With the starter still engaged, actuate the fuel flow by advancing the throttle to Idle. The gas generator should ignite and accelerate to 14,000 RPM within 5 seconds.

(f) RELEASE the starter after 5 seconds or upon reaching Idle RPM.

(g) Oil pressure must be above 55 PSIG. Shutdown if below this limit.

CAUTION: If the gas generator fails to reach idle speed within 5 seconds, close the fuel valve and continue cranking the engine. This action will permit clearing the combustion and turbine sections of trapped fuel and reduce the fire hazard.

After two successive attempts to start the engine, allow the starter to cool for twenty minutes before re-energizing.

Normal Operation:

Upon reaching Idle RPM, lock the throttle and survey all engine instruments. Enter the run-up area and inspect the engine for fuel and oil leakage. Look for loose wiring.

After insuring that no personnel are in the run-up area, advance to Maximum Power with the propeller in flat pitch, and check the gas generator RPM and the exhaust gas temperature. These values should not exceed 36,000 RPM and 1200°F respectively. If an over-limit condition exists, then adjust the high-speed stop on the fuel control governor. In addition, if the oil pressure is above 70 PSI then adjust the oil pump pressure relief valve.

The following limits have been established for engine operation with the propeller at flat pitch. If any of these limits are exceeded, the engine should be stopped and the cause investigated and corrected.

Gas Producer RPM	Starting	4500 rpm		
	Idling	140000rpm		
	Rated Speed			36000 rpm
	Take-off			37700 rpm
Propeller RPM	Rated			2300 rpm
	Take-off			2450 rpm
	Maximum			2750 rpm
Fuel Pressure	Starting	35 psi	100 psi	200 psi
	Rated Speed		340 psi	500 psi
Oil Pressure	Starting	20 psi		
	Rated Speed	30 psi		80 psi
Oil Temperature	Rated Speed			200°F
Exhaust Gas Temp.	Continuous			1200°F
	Take-Off			1300°F

The engine may be stopped at any time in the following manner:

(a) Retard throttle to Idle and cool the engine for 3 minutes.

(b) Turn the DC power switch OFF.

(c) Move the fuel control to OFF position.

Data Analysis:

The horsepower output of this propulsion system may be calculated from the following:

$$HP = (2\,\pi/33{,}000)\ (\text{Torque-Ft-Lbs.})\ (\text{Propeller RPM})$$

The torque is obtained directly from Figure 10.

The actual thrust must be derived by using the equation of moments about the centerline of the flexure support. The exhaust gas vertical force component must be obtained from the exhaust velocities and the airflow data presented in Figure 13. The dimensions of the various moment-arms are also given on the figure. The load cell applied thrust values may be obtained from the calibration curve, Figure 9. The moment equation becomes;

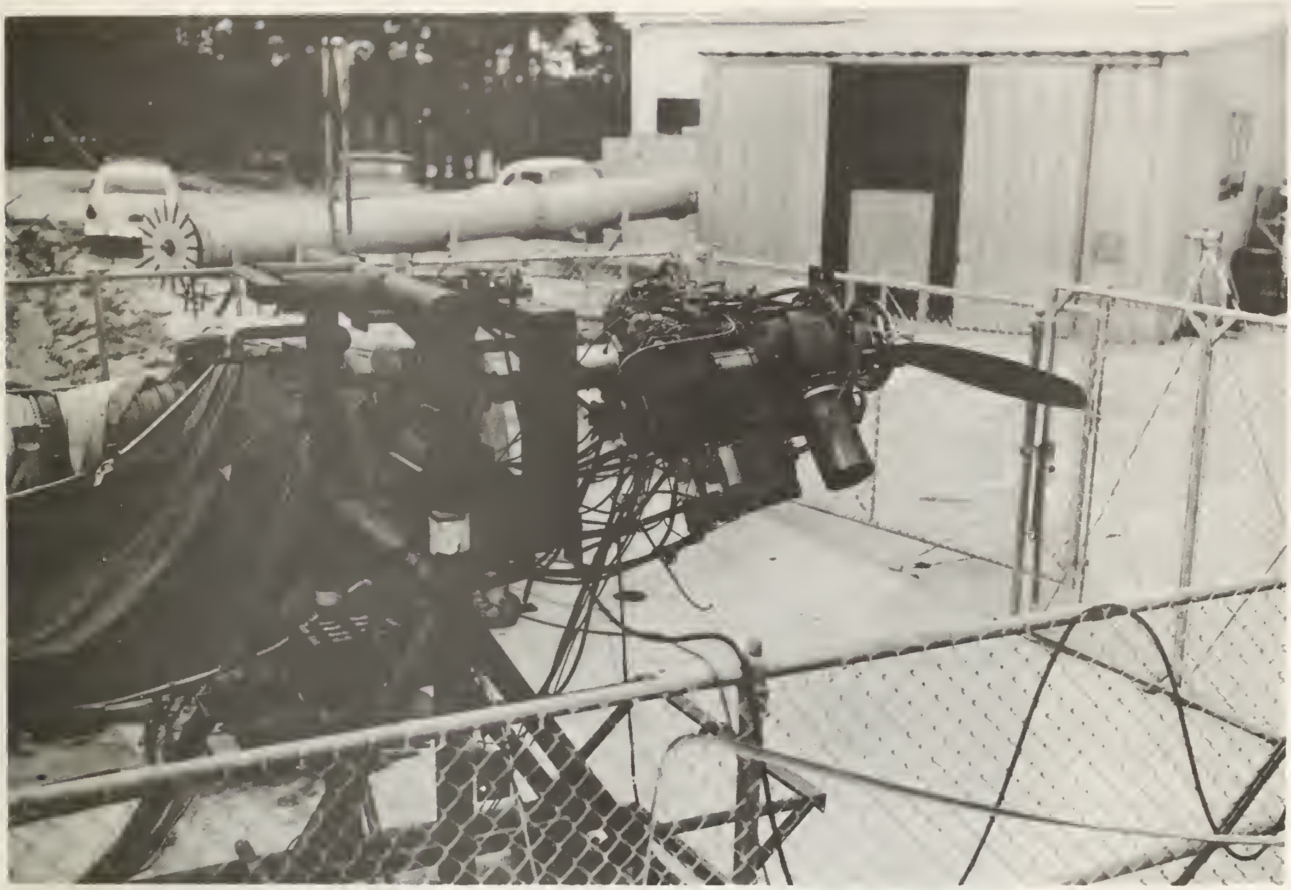
$$21.125'' \times (F_{g_{actual}}) = 47.50'' \times (F_{vertical}) + 33.625'' \times (F_{g_{load\ cell}})$$

Calculation of the propeller efficiency and the power coefficient can be estimated since BHP and F_g are known. However data covering this Beech propeller is not available for comparison at this time. It is suggested that any comparison be made with the data presented by Webb and Willer in the Marks Mechanical Engineers Handbook, Sixth Edition, page 11-109, Figure 6.

All other engine instrumentation parameters need no further analysis. All data should be corrected to Standard Sea Level conditions. The engine performance specifications are exhibited in Figure Nos. 11 and 12.

The following data is included to permit a more complete cycle analysis of the propulsion system:

Fuel Specific Gravity	.780
Fuel FTU Content/Lb	19,000
Compr. Inlet Area	22.28 sq. in.
Compr. Disch Area (per duct)	8.21 sq. in.
Gas Gen Turb. Inlet Area	111.00 sq. in.
Power Turb. Inlet Area	21.00 sq. in.
Exhaust Gas Area (per duct)	40.70 sq. in.

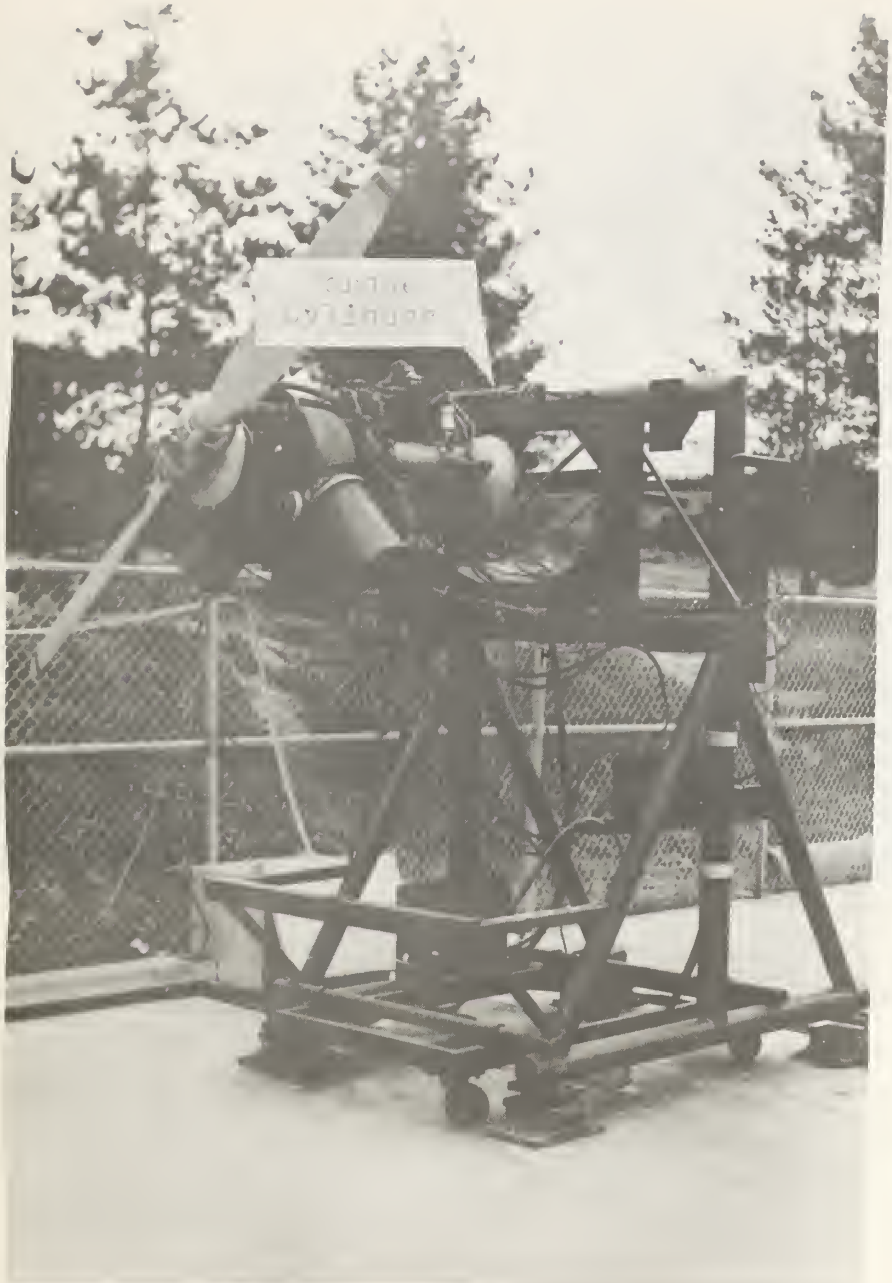


General Arrangement of the Turbonron Test Facility

Figure No. 1

[illegible] Engine and Propeller

Figure No. [illegible]



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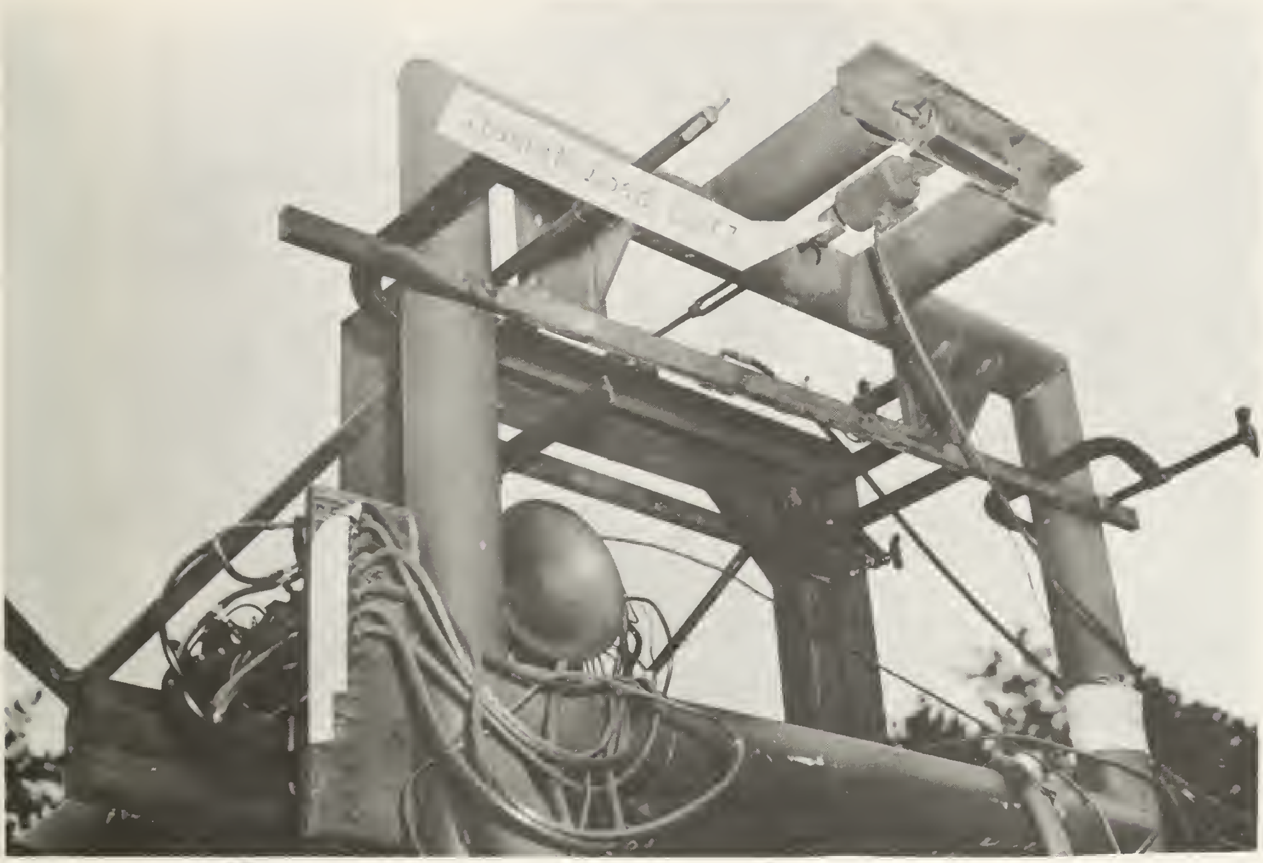
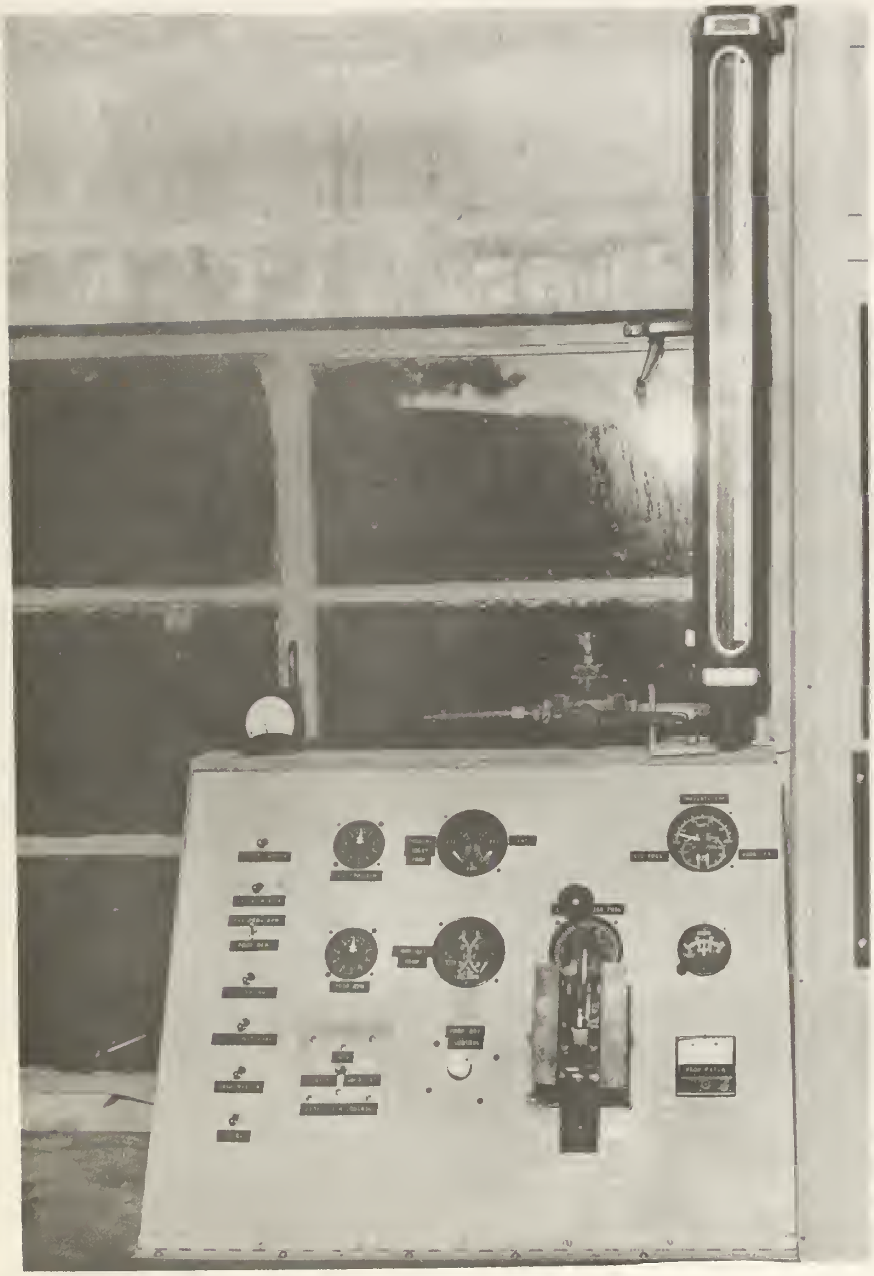


Torque and Thrust Indicating Systems

Figure No. 4

Engine, Control Area and Protective Wall

Figure No. 5

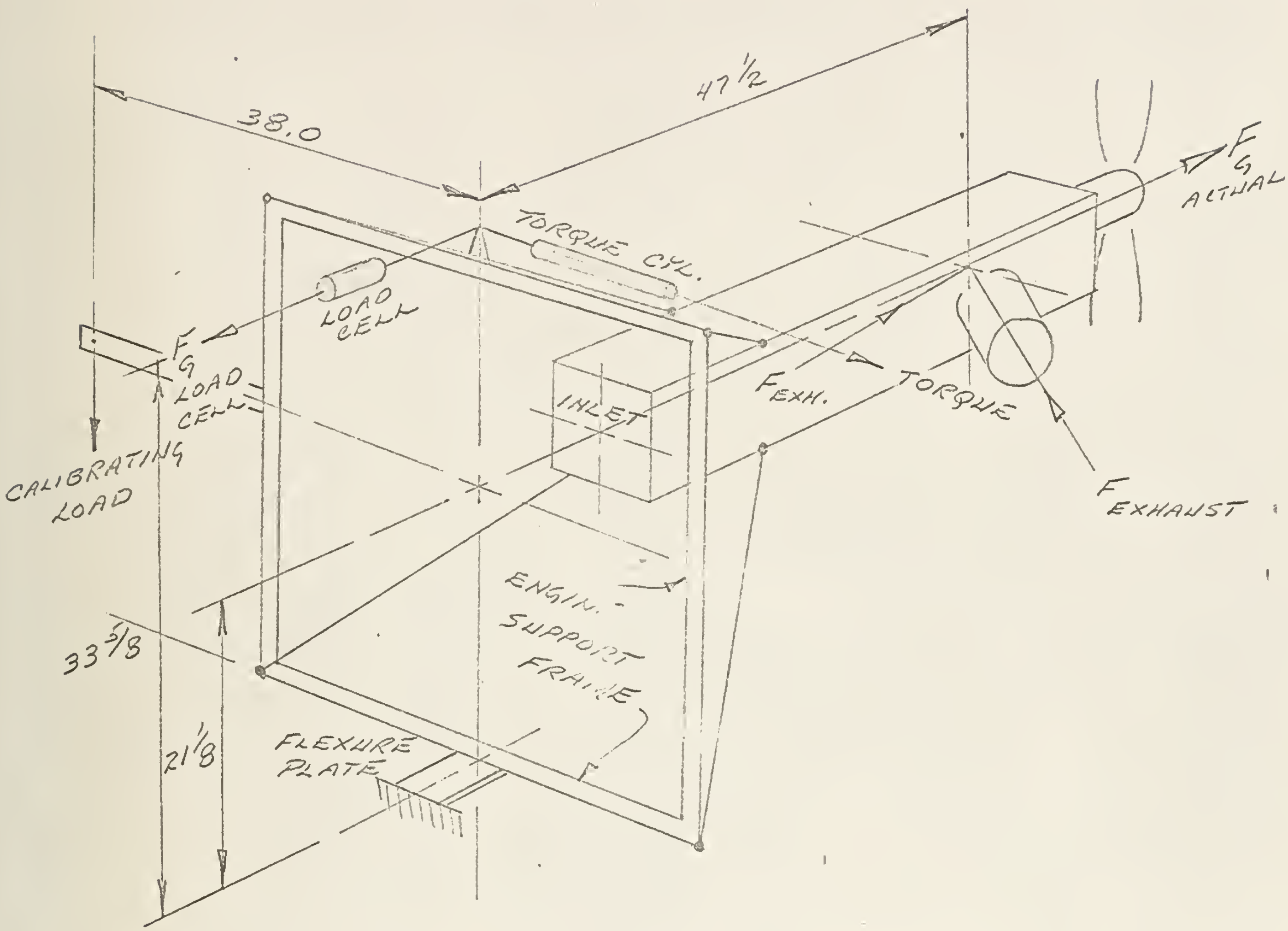


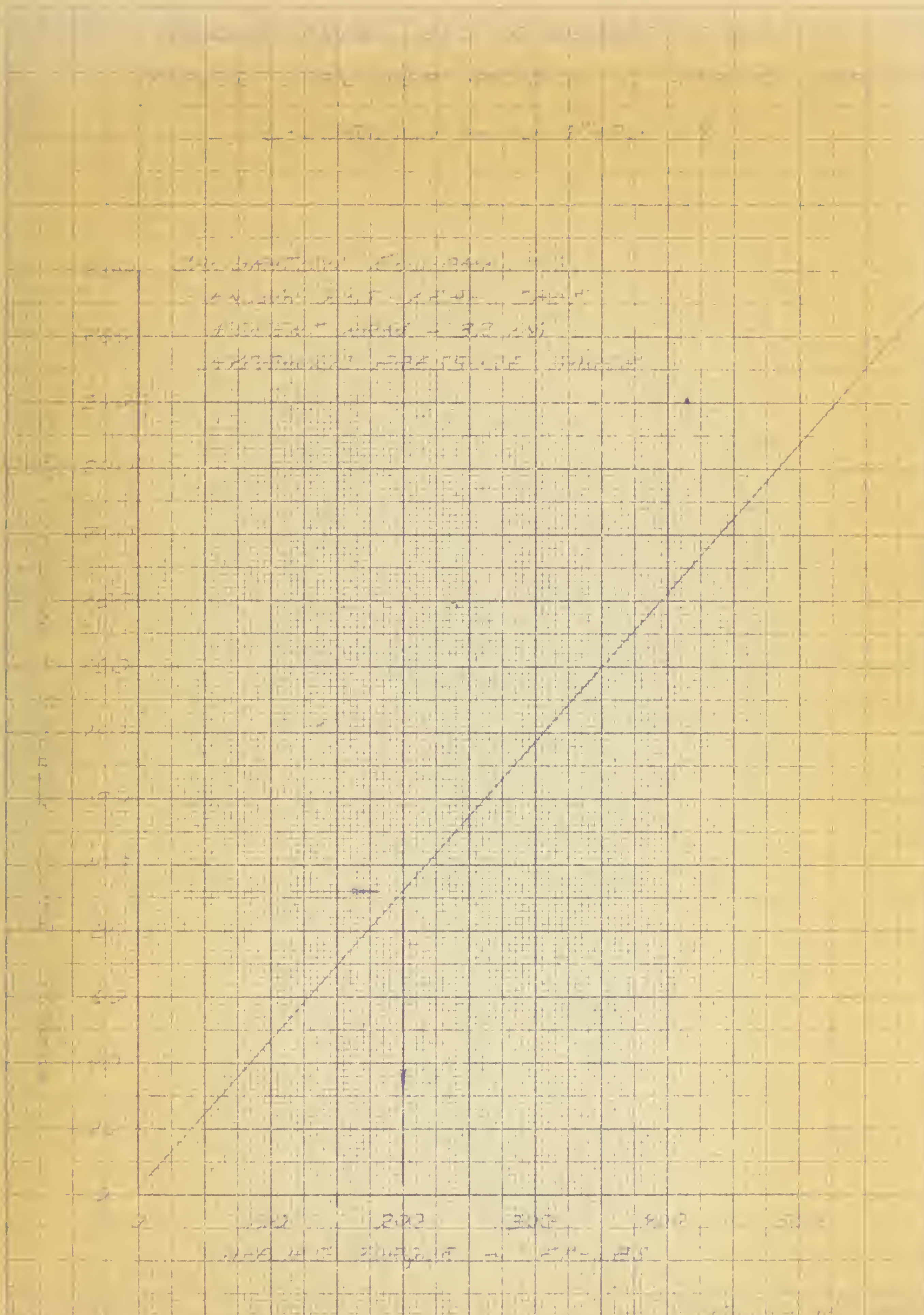
Engine and Propeller Control Panel

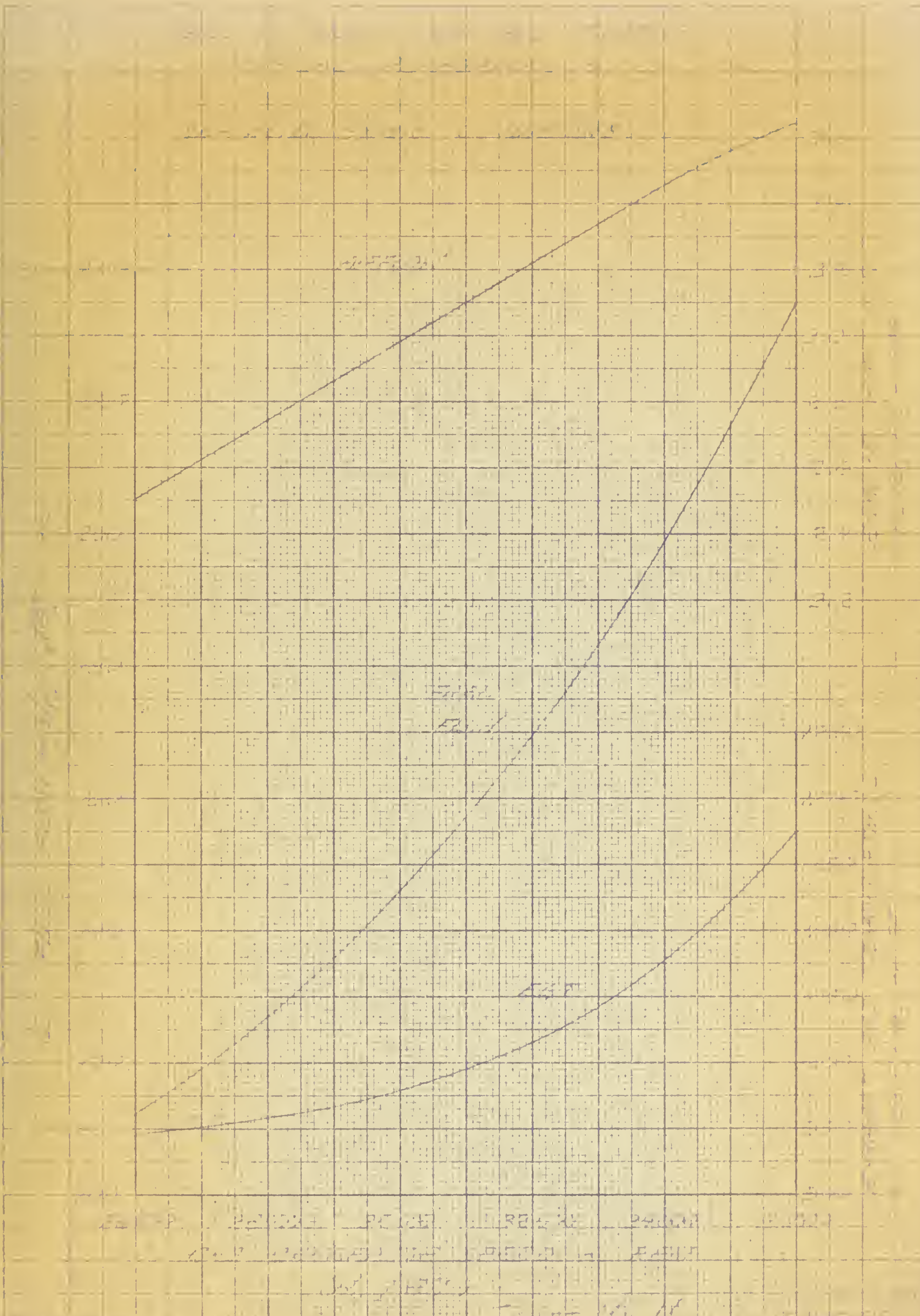
Figure No. [illegible]

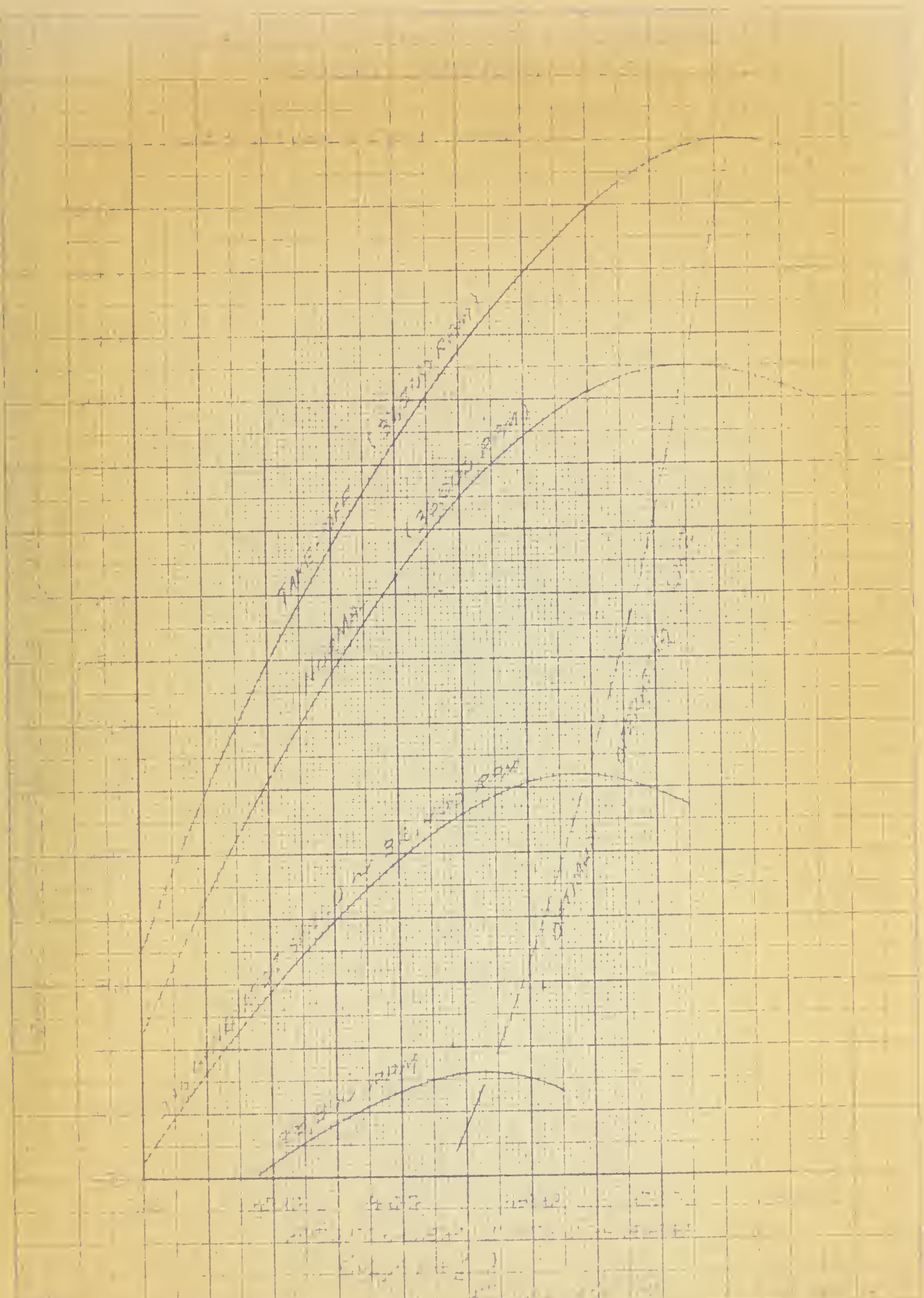
THRUST AND TORQUE MEASURING SYSTEM SCHEMATIC

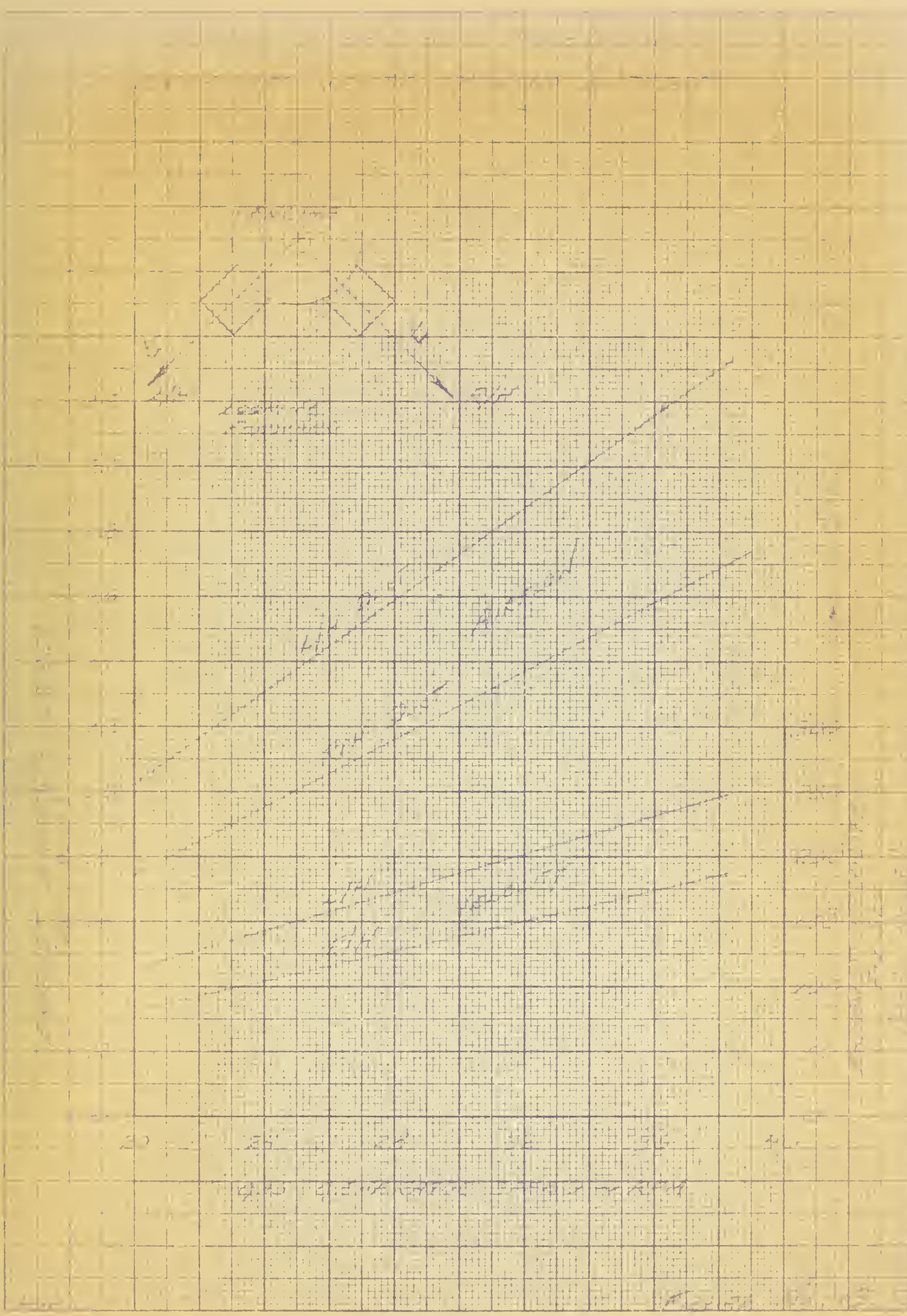
Figure No. 8

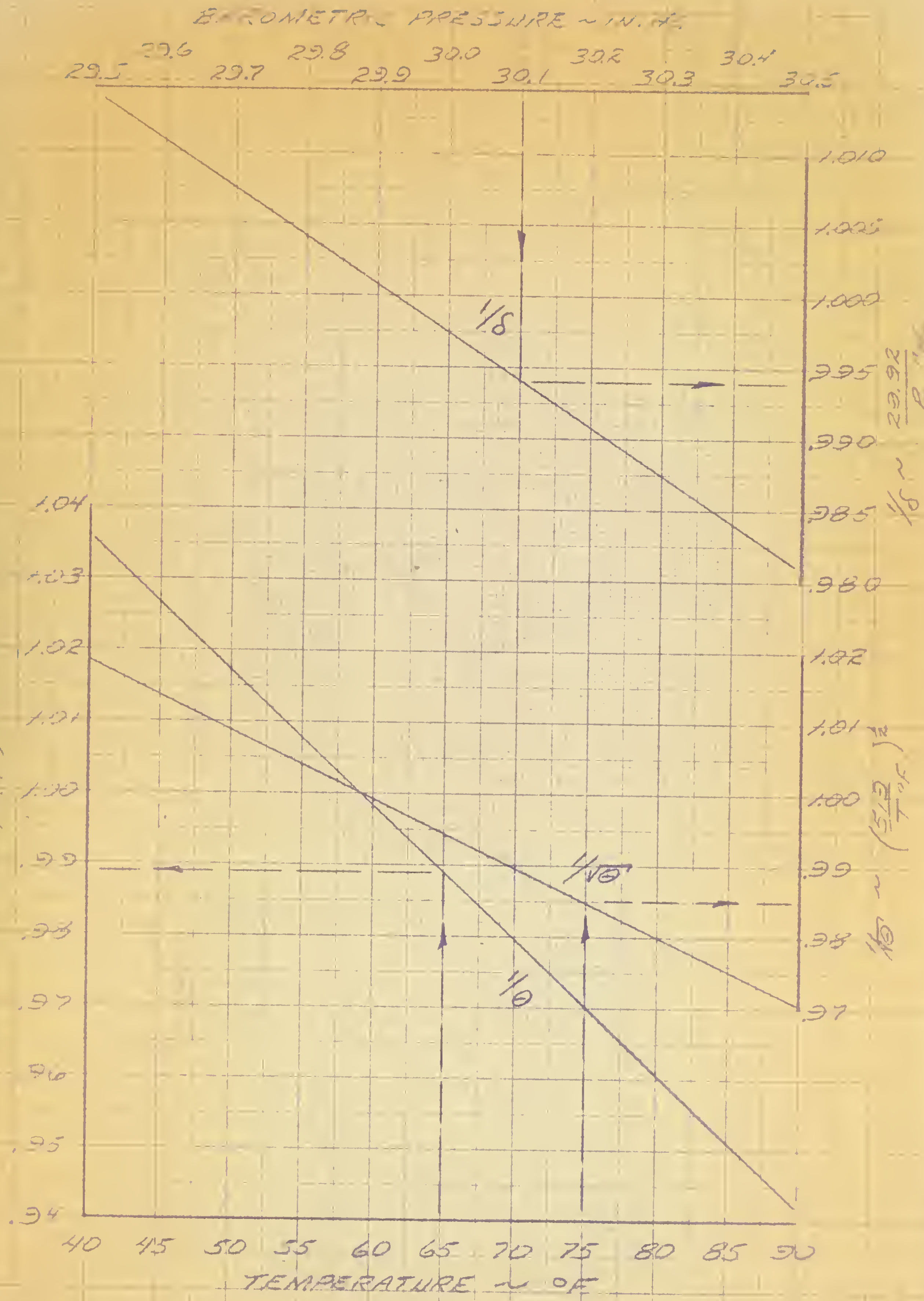











BAROMETRIC PRESSURE ~ IN. HG.
29.5
29.6
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1/δ
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1.04
1.03
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.96
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.94
1/θ ~ 519/T (°F)
1/√θ
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.99
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1/√θ ~ (519/T °F)^½
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70
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85
90
TEMPERATURE ~ °F

Turboprop
Engine
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